UNIVERSITI PUTRA MALAYSIA

COMPARISON OF SKULL DIMENSIONS AND THEIR RESPECTIVE DENTITION IN RELATION TO ITS BITING FORCES IN ROTTWEILER, DOBERMANN, GERMAN SHEPHERD AND LOCAL DOGS IN MALAYSIA

JESSIE BAY JI XI

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JESSIE BAY JI XI

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CERTIFICATION

It is hereby certified that I have read this paper entitled, “Comparison of Skull Dimensions and their Respective Dentition in relation to their Biting Forces in Rottweiler, Dobermann, German Shepherd and local dogs in Malaysia” by Jessie Bay Ji Xi, and in my opinion it is satisfactory in terms of scope, quality and presentation as partial fulfillment of the requirement for the course VPD 4999 – Project.

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DEDICATION

TO MY DEAREST PARENTS, BROTHER AND FRIENDS.

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LIST OF ABBREVIATIONS

CBF	Canine Biting Force
MBF	Molar Biting Force
RI	Right Incisor
LI	Left Incisor
RC	Right Canine
LC	Left Canine
RPM	Right Premolar
LPM	Left Premolar
RM	Right Molar
LM	Left Molar

ABSTRACT

An abstract of the project paper presented to the Faculty of Veterinary Medicine in partial requirement of the course VPD 4999 – Project.

COMPARISON OF SKULL DIMENSIONS AND THEIR RESPECTIVE DENTITION IN RELATION TO THEIR BITING FORCES IN ROTTWEILER, DOBERMANN, GERMAN SHEPHERD AND LOCAL DOGS IN MALAYSIA

By

Jessie Bay Ji Xi

2015

Supervisor: Associate Prof. Dr. Shanthi Ganabadi

Co-supervisor: Dr. Gayathri Thevi Selvarajah

Since the beginning of domestication, the craniofacial architectures of dogs (*Canis lupus familiaris*) have changed and modified of a result of human intervention in natural selection. Fatal attacks in humans by dogs have highlight the importance of studying comparative anatomy in forensic science to identify the specific dog breed involved in such an attack. Several studies described the biting forces for specific breeds, but thus far, no such investigation has been conducted in local dogs of Malaysia. Thus, the purpose of this study is to determine the skull dimensions and dentition to estimate and compare the biting forces in Rottweiler, Dobermann, German Shepherd and local dogs in Malaysia. Twenty skulls were obtained from male dogs (five from each different breed) that were disposed at the Post-Mortem Laboratory at the Faculty of Veterinary Medicine, Universiti Putra Malaysia. Skull dimensions were measured using a pair of Vernier caliper on defleshed-dried skulls. Bite forces were estimated using the lever model adapted from Kiltie, 1984. Increasing zygomatic width has a stronger correlation (p<0.01) with biting forces compared to skull length. Rottweiler has the strongest biting forces, compared to Dobermann and German Shepherd. The local dogs have the smallest zygomatic widths, thus the canine and molar biting forces are the weakest. Local dogs are relatively smaller (p<0.05) compared to the other three breeds in terms of skull dimensions and dentition; therefore resulting in the lowest biting forces. The present study revealed that each breed has a distinct skull dimension, dentition and biting forces comparable to other published reports. Due to the high variation observed among local dog in terms of body and skull sizes and overall appearances; future studies should include higher number of local dogs to establish a database of skull dimensions and bite forces which can be valuable information for Malaysian local forensics and crime investigators.

Keywords: bite force, dogs, skull dimensions

ABSTRAK

Abstrak daripada kertas projek yang dikemukakan kepada Fakulti Perubatan Veterinar untuk memenuhi sebahagian daripada keperluan kursus VPD 4999 – Projek.

PERBANDINGAN DIMENSI TENGKORAK DAN KEGIGIAN BERHUBUNG DENGAN DAYA GIGITAN ANTARA ROTTWEILER, DOBERMANN, GERMAN SHEPHERD DAN TEMPATAN DI MALAYSIA

Oleh

Jessie Bay Ji Xi

2015

Penyelia: Prof. Madya Dr Shanthi Ganabadi

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Dengan bermulanya pembela jinakan, reka bentuk kraniofasial anjing mula berubah dan terubah suai akibat campur tangan manusia dalam pemilihan alam. Serangan maut anjing terhadap manusia telah menunjukkan betapa pentingnya kajian anatomi perbandingan dilakukan dalam bidang sains forensik untuk mengenal pasti baka anjing tertentu yang terlibat dalam sesuatu serangan maut tersebut. Walaupun ada beberapa kajian telah menghuraikan daya gigitan baka anjing tertentu, kajian seumpama belum pernah dijalankan terhadap anjing tempatan Malaysia. Oleh itu, tujuan kajian ini adalah untuk menentukan dimensi tengkorak dan kegigian bagi tujuan penganggaran dan perbandingan daya gigitan antara anjing Rottweiler, Dobermann, German Shepherd dan tempatan di Malaysia. Dua puluh buah tengkorak anjing jantan (5 tengkorak daripada setiap baka) telah perolehi daripada Makmal Post-Mortem, Fakulti Perubatan Veterinar, Universiti Putra Malaysia. Dimensi tengkorak kering ternyah kulit dan daging diukur mengguna sepasang angkup Vernier. Daya gigitan dianggarkan menggunakan model lever Kiltie 1984. Lebar zigoma telah menunjukkan korelasi lebih tinggi ($p<0.01$) dengan daya gigitan daripada panjang tengkorak. Anjing Rottweiler mempunyai daya gigitan yang lebih kuat daripada anjing Dobermann atau German Shepherd. Lebar zigoma anjing tempatan adalah paling kecil; justeru daya gigitan taring dan molarnya juga paling lemah. Anjing tempatan mempunyai dimensi dan kegigian paling kecil ($p<0.05$) di kalangan anjing yang dikaji; ini juga membuatkan daya gigitannya paling lemah. Kajian ini menunjukkan bahawa setiap baka anjing ini mempunyai dimensi tengkorak, kegigian dan daya gigitan sama seperti yang telah dilapor. Oleh sebab ada banyak kelainan saiz badan dan tengkorak dan penampilan keseluruhan di kalangan anjing tempatan, maka kajian masa hadapan perlu melibatkan bilangan anjing yang banyak untuk penubuhan pangkalan data dimensi tengkorak dan daya gigitan anjing tempatan sebagai matlumat rujukan bagi penyiasat jenayah dan forensik Malaysia..

kata kunci : daya gigitan, anjing dimensi

1.0 INTRODUCTION

It is believed that people and wolves have had a long association, as the archeological remains which dated about 12,000 years, by the evidence of a puppy skeleton buried together with humans (Morey 1994). It is believed that domestication of dogs' progenitor, gray wolf and further human intervention in natural selection has created the domestic dogs that we recognized today.

Among land mammals, domestic dogs exhibit the most variation and diversity morphologically. We can appreciate the differences from their height, their body size, leg length etc. For instances, Great Dane can be more than fifty times greater in weight and height compared to a Chihuahua, Pug is known for its flat, shorten snout while Saluki has long snout. The difference in the morphology has leaded us to ponder whether there is any difference in the skull dimension, dentition as well as biting forces among these breeds.

Studies revealed that there are genes which control the craniofacial dimension development, for example the Bone Morphogenesis Protein 3 (BMP3) (Schoenebeck *et al.*, 2012). BMP3 is the gene that determines the diversity of the phenotypes including body size, leg length (Rimbault & Ostrander, 2012). Therefore, based on the BMP3 genes studies, the differences on the craniofacial dimensions have lead to studies on how cranial dimension can affect the biting force.

In mammals, studies on biting force suggested relevant relationship between diet and feeding behavior (Christiansen & Wroe, 2007). Carnivores with bigger body size were estimated to exert higher forces compared to herbivores and omnivores (Christiansen & Wroe, 2007) as carnivores' skull and mandible must be strong enough to hold their prey and prevent them from escaping the attack (Thomason, 1991).

According to Ellis and company in 2009, biting forces increase with the increase in skull size. Other than that, comparative anatomy in forensic anthropology plays an important role in determining whether the assault is from a human or a dog. Dogs have had involved in fatal attacks and death, hence by looking and comparing the available dentition may actually lead us to the potential offending dog. In medium and large skulls, it appears that brachycephalic dogs convey a greater biting force advantage, resulting a higher biting force values for these dogs (Ellis *et al.*,2009).

There is a lack of similar studies done on Malaysian local dogs and this study will provide a preliminary data on skull dimension, dentition and biting forces of local dogs in Malaysia. The purpose of this study is to measure skull dimensions, dentition and biting forces in Rottweiler, Dobermann, German Shepherd and local Malaysian dogs. The hypothesis are: each breed of dog has distinct dimensions for skull, dentition and biting forces and among the four breeds, Rottweiler has the highest biting force.

2.0 LITERATURE REVIEW

2.1 Evolutionary of Dog Domestication

There has been a great evolutionary change in our lifestyle and animal domestication is part of this evolutionary leap. According to Morey 1994, it is believed that people and wolves have had a long association, as the archeological remains which dated about 12,000 years, shows evidence of a puppy skeleton buried together with humans. Men domesticated dogs by adopting the pups into their tribes and feeding them and in return, when the pups grow up, they help in hunting as well as in guarding the tribe. This implies that humankind at that time began to value the potential benefits of domesticating animals and plants (Morey, 1994)

On the other hand, it was also believed that people opted domestication when there was an increase in human population or environmental changes that reduced the availability of food. In the domestic setting, at some point, the wolves began to change both physically and behaviorally, to what we recognize today (Morey, 1994). As dogs become more domesticated, people started to selectively breed them. All of these can be due to the process of genetic selection, positive selection for tameness, tractability, submissiveness, tolerance towards stress, demonstration of affection, and juvenile features have placed new pressures on the emerging domestic dogs (Evans, 1993). This can be seen as that people at that time might have considered smaller animals more manageable as household pets and they also require lesser amount of food compared to larger animals.

2.2 Wild dogs

Wild dogs are also known as feral dogs or mongrels, they are not owned by people and living like wild animals. They have mixed origins and their appearances might resemble the pure breeds such as Doberman, Rottweiler and many more breeds. However, at present and locally, the mongrel dogs has become a popular choice for pets as there are more awareness on adopting instead of buying dogs as pets. Besides that, these dogs can be very loyal and are capable of becoming a good household pets just like any other known pure breeds.

One of the examples of wild dogs will be dingoes in Australia. Dingoes are dogs that were introduced to Australia less than 12,000 years ago as domestic dogs and eventually became fully established as feral population (Evans & Miller, 1993). In Malaysia, we have our wild dogs named Telomian, named after the Telom river. They originally were kept and bred by orang asli (natives to Malaysia) as hunting dogs.

2.3 Skeleton

The skeleton of the body serve as a support as well as to protect internal vital organs, besides providing surfaces for muscles attachments. Bones are classified according to their shape, structure, function, origin or position. Based on shape, there are five general divisions, namely the long, short, sesamoid, flat, and irregular bones. There are three divisions for the bones of the skeleton system classified by using position; which are: the axial, appendicular and heterotopic skeletons. For the axial skeleton, it comprised of a total of 50 bones in the vertebral column; 50 bones for skull and hyoid; and 34 bones for ribs and sternum. As for the appendicular skeleton, 90 of the bones form the thoracic limbs while 96 form the pelvic limbs. Os penis is the only bone that forms the heterotopic skeleton (Evans & Lahunta, 2013).

There are two types of bone structures, namely the compact bones and the spongy bones. The compact bones form the outer shell of all skeletons while spongy in the extremities of long bones, bones of the thoracic and pelvic girdles. Bones serve mainly to support the body, protecting vital organs such as heart, lungs and etc. other than that, by serving as an attachment for different skeletal muscles, bones serve as leverage too. Next, bone helps in the production of red blood cells and some white blood cells. Lastly, it stores calcium and phosphorus (Miller, Evans & Christensen, 1979).

2.4 Skull

Among the three divisions of the skeleton system classified using position: the skull, hyoid bones, vertebrae column, ribs and sternum makes up the axial skeleton. Skull is then divided into cranial region and facial region. Cranial region comprised of bones that cover the brain while facial region include bones that surround the eyes, respiratory and digestive passageways (Evans & Lahunta, 2013). There are three types of skull based on their shape, namely the dolicocephalic, mesaticephalic and brachycephalic. According to Evans and Lahunta in 2013, dolicocephalic dogs are dogs with long and narrowed headed (examples are Collies, Afghan Hounds, Salukis); mesaticephalic dogs are dogs with head of medium proportions (examples are Chow Chow, Doberman, Maltese) and brachycephalic dogs have a short and wide headed (examples are Pug, Pekingese, Bulldogs, Shar Pei).

2.4.1 Bones of the Cranium

Bones that makes up the cranium consists of flat bones. Some of these bones are paired and some are not paired (Evans & Miller, 1993). The unpaired occipital bone is the bone that forms a ring around the junction of medulla oblongata and the spinal cord. The ring can be divided into four parts: a squamous part dorsally, two lateral condylar parts, and a basilar part centrally (Evans & Lahunta, 2013). The parietal bone is a paired bone that forms most of the dorsolateral part of the calvarial portion of the cranium. Each parietal bone lies rostrally to the squamous part of the occipital bone and dorsal to the squamous part of the temporal bone (Evans & Lahunta, 2013). Frontal bone is irregular in shape, it is more broad caudally and narrow as it goes rostrally. From the lateral view, it is concaved and it forms the medial wall of the orbit. Caudal to this concavity, it flares to form part of the temporal fossa. Sphenoid bones form the rostral two third of the base of the cranial cavity between the basioccipital caudally and the ethmoid rostrally (Evans & Miller, 1993). Each of the bone consists of a pair of wings and a median body. There are two sphenoid bones, namely the presphnoid and the basisphenoid. Prespenoid is the more rostral bone with orbital wing while basispenoid is the caudal bone with larger wing.

The bone that forms a relatively large part of the ventrolateral wall of the calvaria is the temporal bone (Evans & Lahunta, 2013). In a young animal, it can be separated into three parts, petrosal, tympanic and squamous parts (Evans & Miller, 1993). Petrosal part is where the choclear and semicircular canals found and it is located in the skull. Tympanic part has a sac-shaped protuberance which lies central to themastoid process (Evans & Miller, 1993). The squamous part consist of two divisions, an expanded plate that lies dorsal to the bulla, and the rostrally projecting zygomatic process which forms the caudal half of the zygomatic arch.

Lastly will be the ethmoid bone. This bone can be found in between the cranial and facial part of the skull (Evans & Miller, 1993). It is located in between the walls of the orbits and frontal bone is located dorsal to it, maxilla bone is located lateral to it while vomer bone and palatine bones are located ventral to it (Evans & Miller, 1993).

2.5 Teeth

Dogs are carnivores and their prominent features of their dentition will be their canine teeth. Their upper dental arch is longer than the lower dental arch and it has fewer teeth compared to the lower. There is little contact between the upper and lower teeth except some of the caudal teeth is involved in crushing the food. The formula for temporary dentition in dogs is

$$\frac{3-1-3}{3-1-3} = 28$$

and the formula for the permanent set is

$$\frac{3-1-4-2}{3-1-4-3} = 42$$

Incisor teeth are embedded in the incisive bones and mandible, and their size changes with age due to wear and tear. Wear can helps us in aging a dog. All incisors have a single root, and they are used for nibbling, grooming and when detaching small morsels (Dyce, Sack & Wensing, 2010). There are four premolar teeth, the first one may have either one or two roots whereas the others have two, the upper fourth premolar has three roots (Dyce, Sack & Wensing, 2010). The fourth premolar is larger and more complex than the others. For the molars, the first molar is the biggest and the size decreases as it goes down.

2.6 Variation in Skull Shape

Artificial selection done by human has produced variation in canine skull shape among the dog breeds. Changes in skull shape are also an outcome of domestication. A missence mutation in BMP3 was found nearly fixed among the small brachycephalic dog breeds (Schoenebeck et al., 2012). Mutation and intense selection and breeding based on the desired traits and characteristics causing skull shape to be breed defining, for example Bulldog has been known for their short faces.

2.7 Biting Forces

In mammals, biting forces is related to their feeding behavior and diet. Biting forces have been studied as it helps us to speculate their feeding habits and behavior (Christiansen & Wroe, 2007). Biting forces play an important influence in carnivores due to their flesh eating diet. It is suggested that animals with a larger brain case (Ellis *et al.*, 2009) exerted a higher biting forces as they provide more area for jaw muscles attachments such as masseter muscles, pterygoid muscles and temporalis muscles.

3.0 MATERIALS AND METHODS:

3.1 Collection of samples

Five male skulls were collected from the Anatomy Museum from the Faculty of Veterinary Medicine of Universiti Putra Malaysia from 4 respective species of adult dogs namely Rottweiler, Dobermann, German Shepherd and local Malaysian dogs. The skulls were defleshed using a pair of pilers, bleached and dried overnight at room temperature.

3.2 Measurement

Measurements were obtained using a pair of calipers, a thread and a long ruler on a flat surface. Skull measurements are taken from both dorsal and lateral view. Teeth measurements were taken from both maxilla view and mandible view. Each measurement was repeated three times and average values were calculated.

3.2.1 Skull Measurement

Skull measurements are taken from both dorsal and lateral view. Dorsal view (Figure 1) & Frontal view (Figure 2) measure the total skull length, length measuring from the most caudal end to the nasal end, zygomatic width, lacrimal width and right and left orbital width. As for lateral view (Figure 3), measurements was taken from the height of the occipital lobe till the floor of the mandible, height of nasal frontal till the floor of maxilla, height of most dorsal coronal suture till the floor of mandible, height of nasal tip till floor of maxilla, length of maxilla and length of mandible.

3.2.2 Dentition Measurement

Dentition measurements will be taken from both maxilla view (Figure 5) and mandible view (Figure 6). Measurements are taken by measuring the interarch (distance between each corresponding left and right tooth on maxilla and mandible starting from third incisor to the last molar tooth)

3.2.3 Biting Force Measurement

Biting force will be estimated using one level model adapted from Kiltie, 1984, which is based on the principle of lever mechanism. This lever model estimates the forces produced by the jaw muscles, and the leverage of the force about the point of biting (Ellis *et al* 2009).

$$CBF_1 = (L_m \text{ x } M + L_t \text{ x } T)\ FPA/O_c$$

$$MBF_1 = (L_m \text{ x } M + L_t \text{ x } T)\ FPA/O_m$$

where CBF is the calculated force of biting in Newtons (N) at the canine estimated while MBF is the calculated force of biting in Newtons (N) at the molars; FPA is the force per area unit of muscle which was taken as 300 MPa after (Weijs & Hillen, 1984). Adjustment was done for the lever model

$$\text{Adj. } CBF_2 = 1.781 \text{ x } CBF_1 + 36.94$$

$$\text{Adj. } MBF_2 = 3.504 \text{ x } MBF_1 - 696.3$$

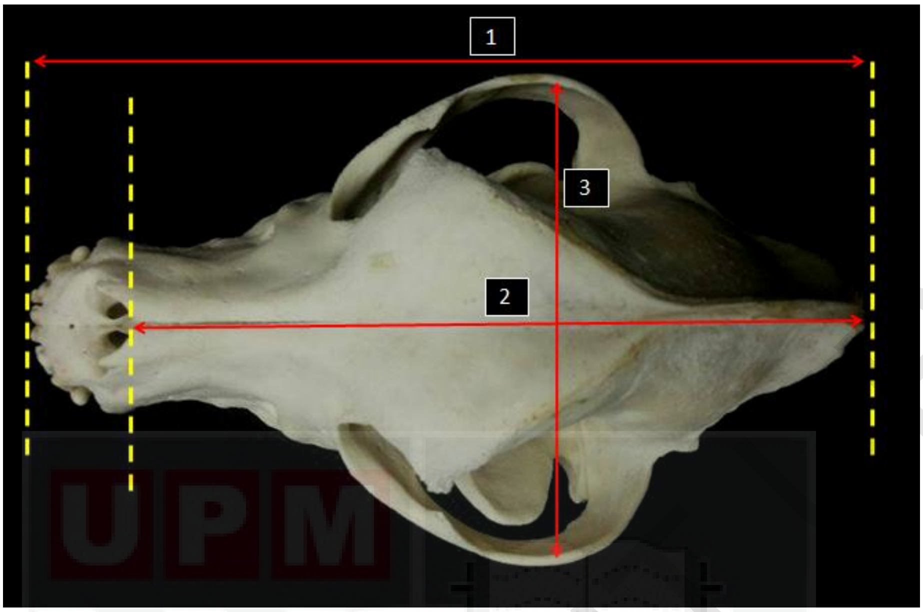

Figure 1: Measurements from a dorsal view of skull.

1 - Total length of skull

2 - Length measuring from caudal end to nasal end 3. Zygomatic width

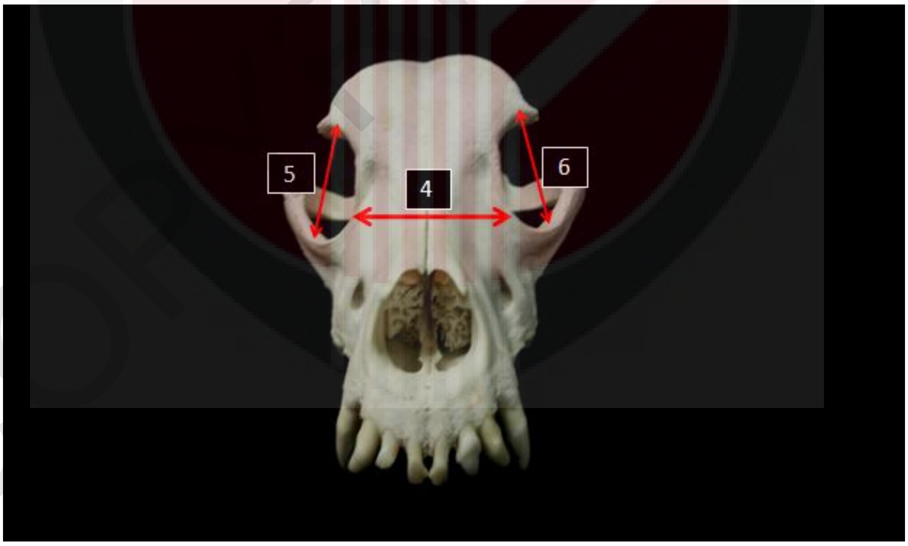

Figure 2: Measurements from a frontal view of skull.

4 - Lacrimal width

5 - Right orbital width

6 - Left orbital width

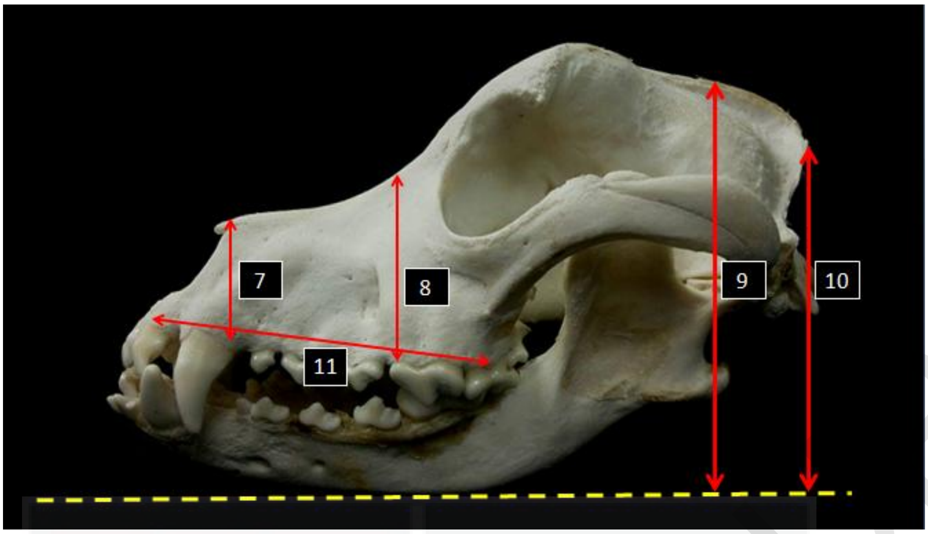

Figure 3: Measurements from the left lateral view of skull.

7 - Height measuring nasal tip to maxilla

8 - Height measuring from nasal frontal till maxilla

9 - Height measuring from most dorsal coronal suture

10 - Height measuring from occipital lobe till floor of mandible

11 - Length of maxilla

Figure 4: Measurements from a left lateral view of mandible.

12 - Length of mandible

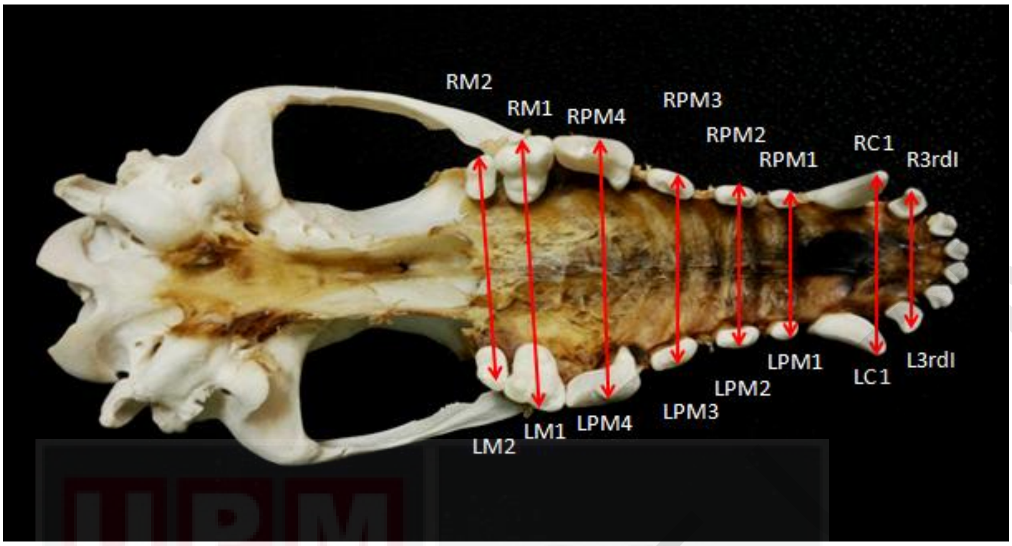

Figure 5: Measurements from the ventral view of maxilla

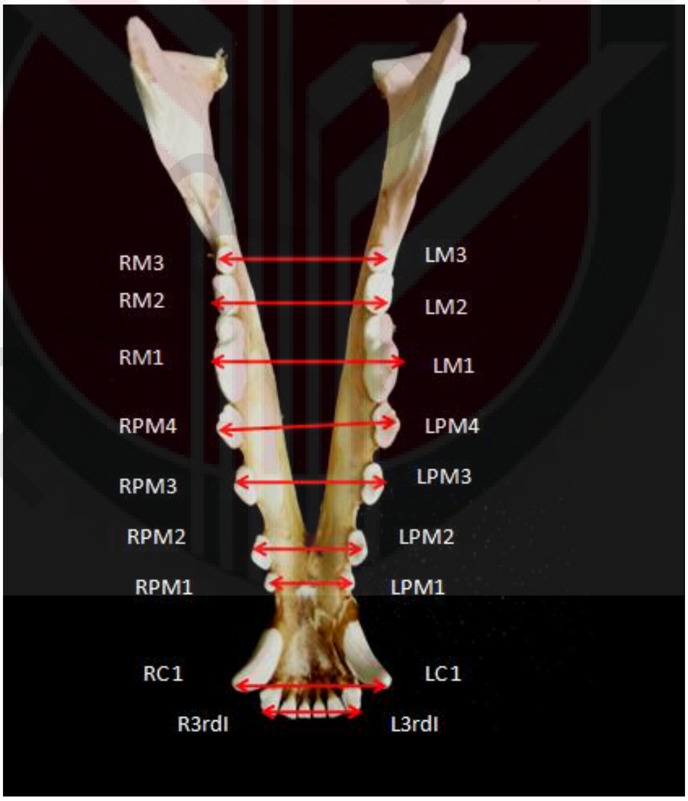

Figure 6: Measurements from the ventral view of mandible

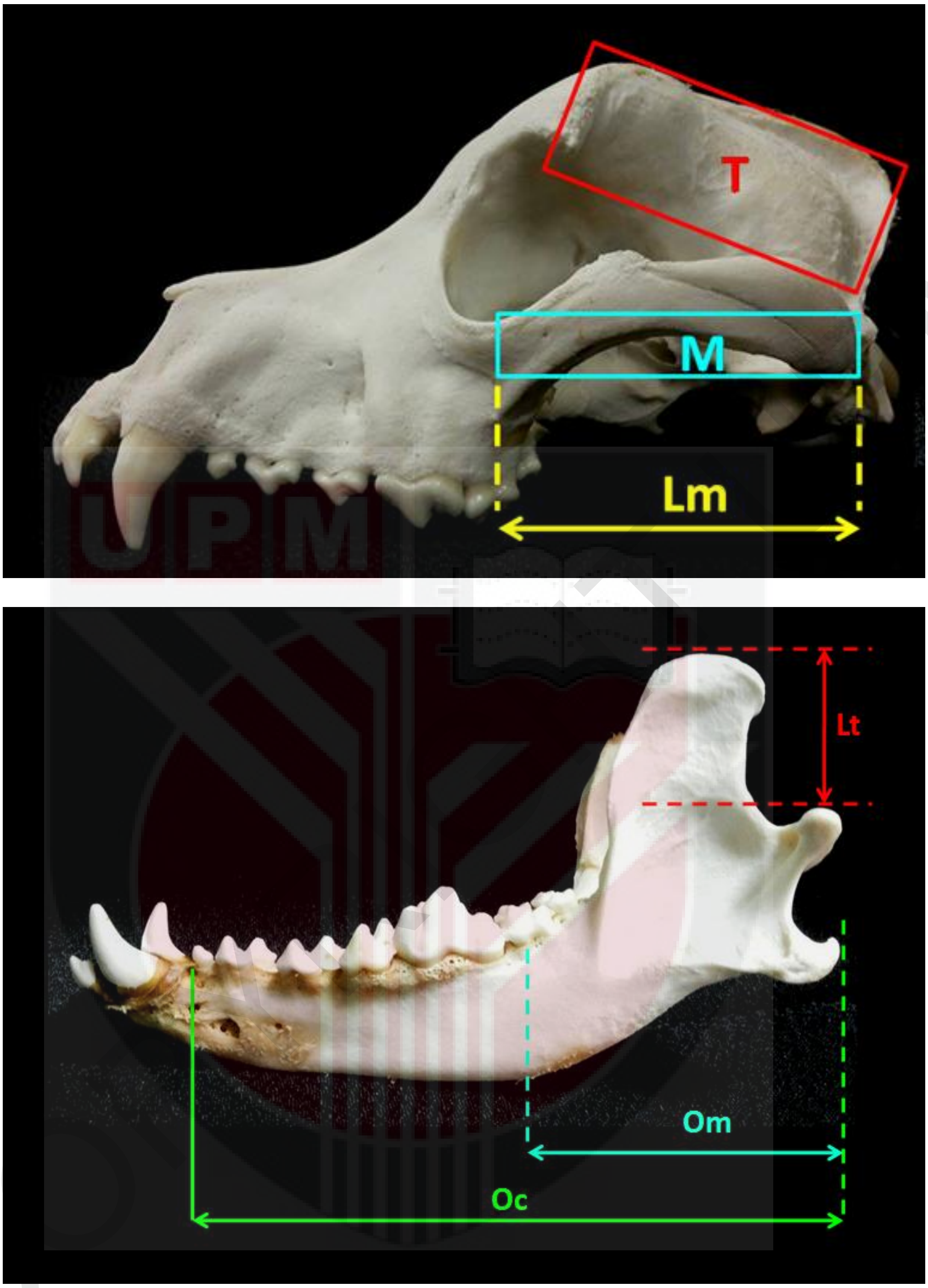

Figure 7a & 7b (the above diagram is 7a and the bottom diagram is 7b): Measurements to calculate biting force. Lm is the length of masseter origination scar on zygomatic arch; Lt is the height of coronoid process above the jaw condyle; M is the area of a rectangular calculated as the product of the length and width of the masseter origination scar on the zygomatic arch, and T is the area of the temporalis origination scar as the product of the length and height of the temporalis fossa

3.3 Statistical Analysis

Data was tabulated into Microsoft Excel spreadsheets. All statistical analysis in this study was performed and box-plots drawn using the software IBM SPSS statistical version 20. The Shapiro-Wilk test was used to find out the normality of the subjects (for less than 50 subjects), Levene Test of Equality of Error was also determine the normality of the variance. Post Hoc Tukey HSD test was then conducted to complete the multiple comparisons between the subjects. Pearson correlation was then used to find out the correlation between the subjects. A p value of less than 0.05 is considered statistically significant where applicable.

4.0 RESULTS

4.1 Skull Dorsal view

4.1.1 Total Length of Skull

There was no significant difference (α=0.05) in terms of the total skull length between the Dobermann and German Shepherd, meaning they have approximately similar skull lengths. The Rottweiler has a significantly shorter skull compared to Dobermann and German Shepherd and longer skull compared to local dogs (Figure 8 and Table 1). Local dogs were found to have significantly shorter skulls compared to the other three breeds (Figure 8 and Table 1).

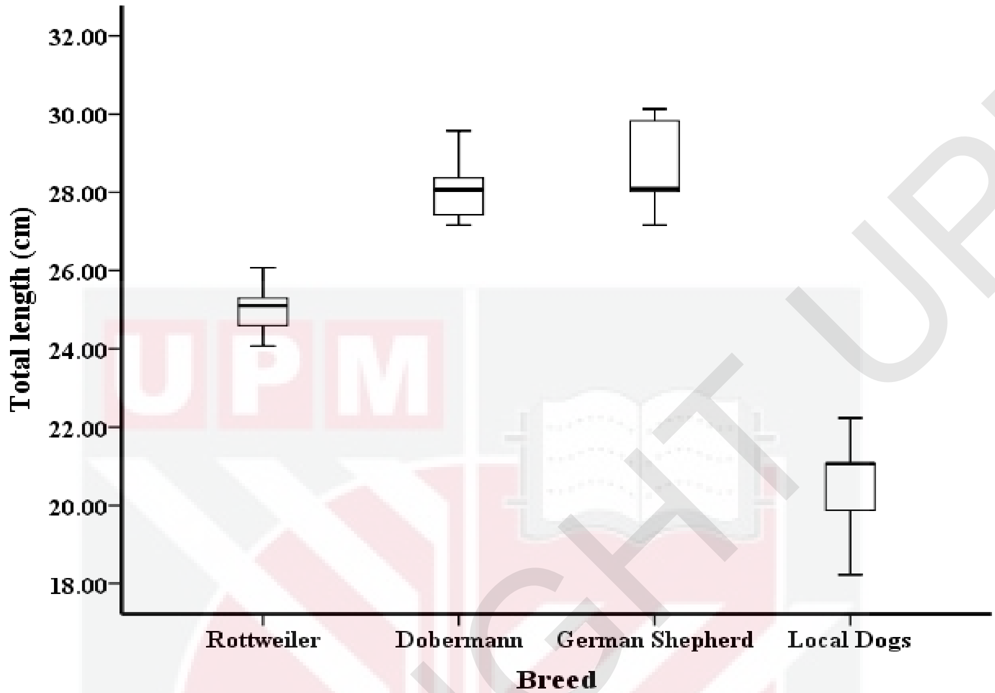

Figure 8: Box-plots of total length of skull in Rottweiler, Dobermann, German Shepherd and local dogs

Table 1: Summary on the p value of total length of skull on the multiple comparisons among the breeds

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.003	0.001	<0.0001
Dobermann			0.886	<0.0001
German Shepherd				<0.0001

4.1.2 Length measuring from the Caudal end to Nasal end

At α = 0.05, there were no significant differences between Rottweiler, Dobermann and German Shepherd while local dogs was significantly shorter in terms of length measuring from the caudal end to nasal end compared to the other three breeds (Figure 9 and Table 2).

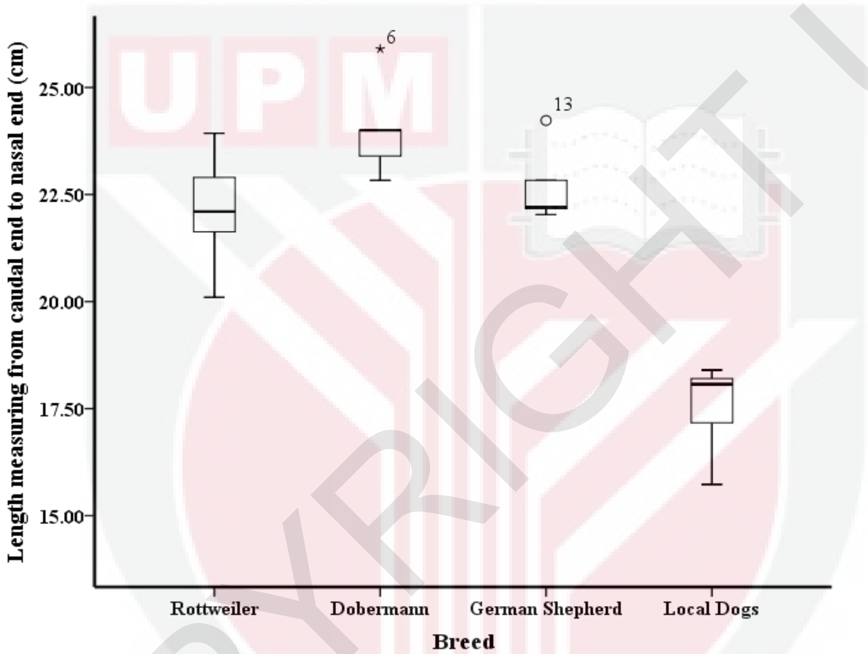

Figure 9: Box-plots of length measuring from caudal end to nasal end in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers

Table 2: Summary on the p value of length measuring from caudal end to nasal end in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.087	0.871	<0.0001
Dobermann			0.305	<0.0001
German Shepherd				<0.0001

4.1.3 Zygomatic Width

At α = 0.05, there were significant difference in zygomatic width measurements between of the Rottweiler compared to collectively both the Dobermann and German Shepherd (Figure 10 and Table 3). In accordance to that, there was no significant difference between the Dobermann and German Shepherd (Figure 10 and Table 3).The zygomatic width of local dogs was found to be the shortest compared to all other three breeds with statistical significance (Figure 10 and Table 3).

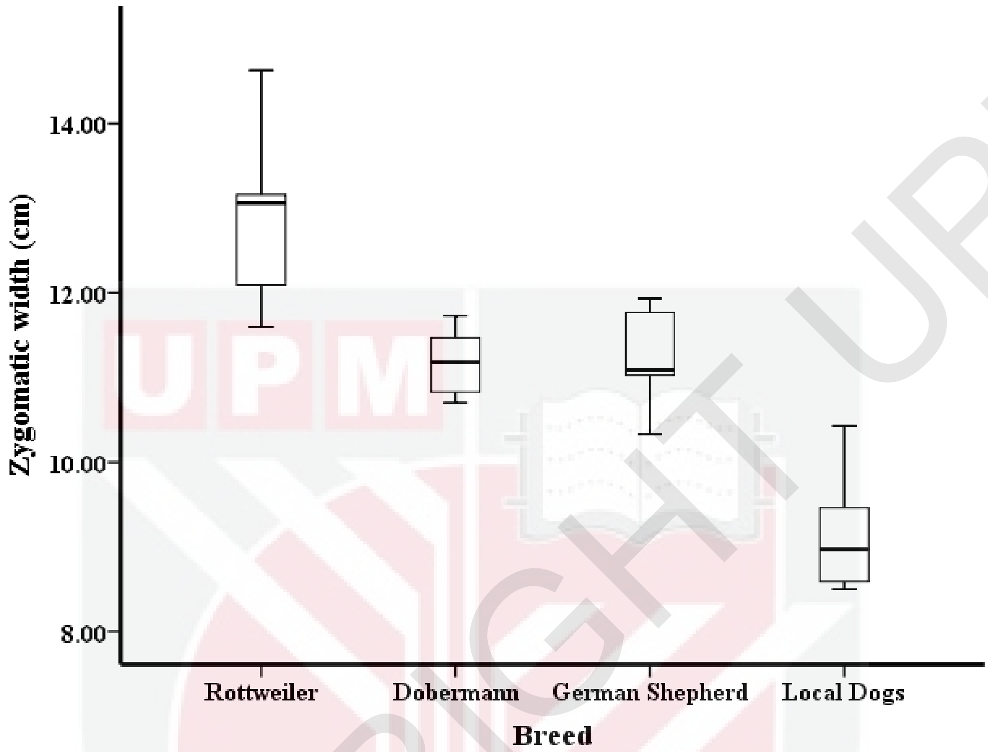

Figure 10: Box-plots of zygomatic width in Rottweiler, Dobermann, German Shepherd and local dogs

Table 3: Summary on the p value of zygomatic width in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.017	0.021	<0.0001
Dobermann			1.000	0.006
German Shepherd				0.005

4.1.4 Lacrimal Width

At α = 0.05, there were no significant differences in lacrimal width among the Rottweiler, Dobermann, German Shepherd dogs while the local dogs was found to have significantly shorter lacrimal widths compared to other breeds (Figure 11 and Table 4).

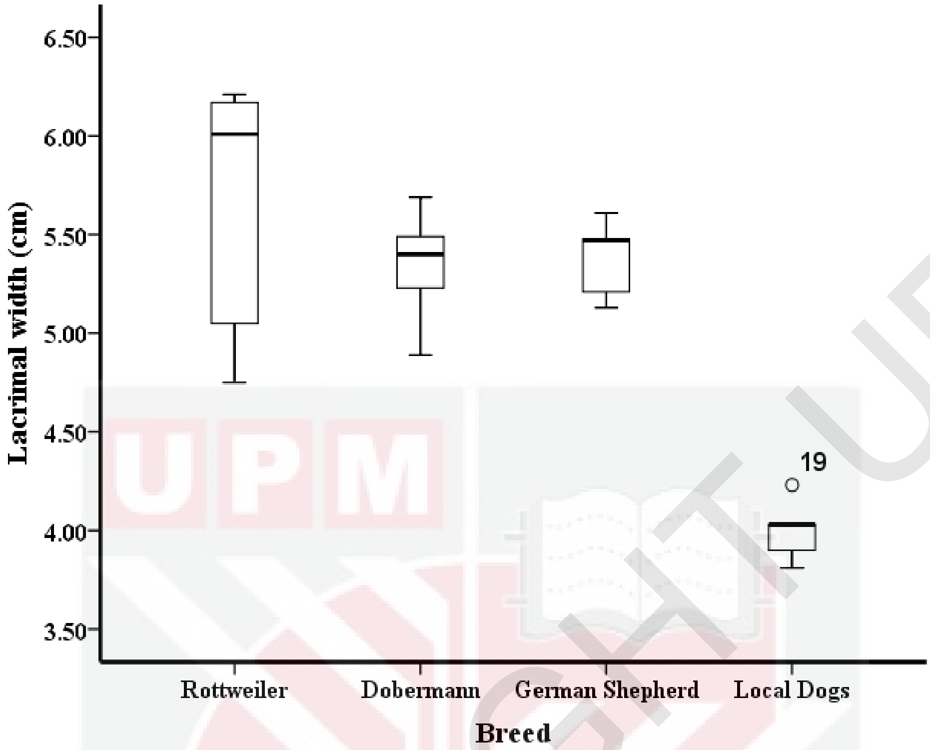

Figure 11: Box-plots of lacrimal width in Rottweiler, Dobermann, German Shepherd and local dogs. Circle is outlier.

Table 4: Summary on the p value of lacrimal width in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.642	0.735	<0.0001
Dobermann			0.998	<0.0001
German Shepherd				<0.0001

4.1.5 Right Orbital Width

At α = 0.05, there were no significant differences in right orbital width among the Rottweiler, Dobermman and German Shepherd while local dogs were found to have significant shorter right orbital width compared to other breeds except Dobermann. (Figure 12 and Table 5).

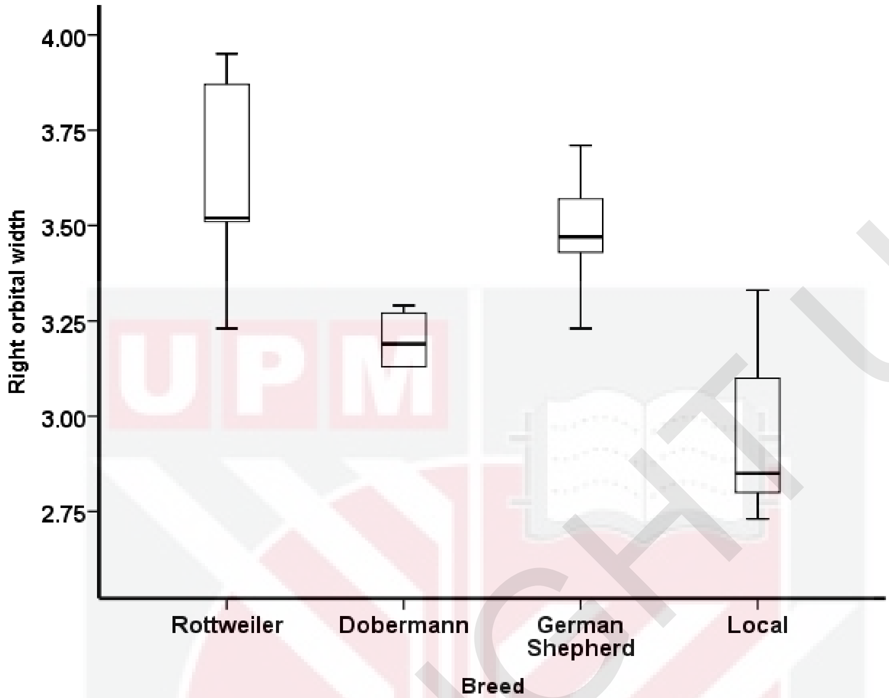

Figure 12: Box-plots of right orbital width in Rottweiler, Dobermann, German Shepherd and local dogs

Table 5: Summary on the p value of right orbital width in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.035	0.760	0.001
Dobermann			0.209	0.326
German Shepherd				0.007

4.1.6 Left Orbital Width

At α = 0.05, there are no significant differences in left orbital width in Rottweiler, Dobermann and German Shepherd (Figure 13 and Table 6). There was significant difference in terms of left orbital width comparing the local dogs to the Rottweiler and German Shepherd, where the local dogs were found to have the shortest width (Figure 13 and Table 6). No statistical significance was noted when comparing the left orbital width of local dogs to the Dobermann (Figure 13 and Table 6).

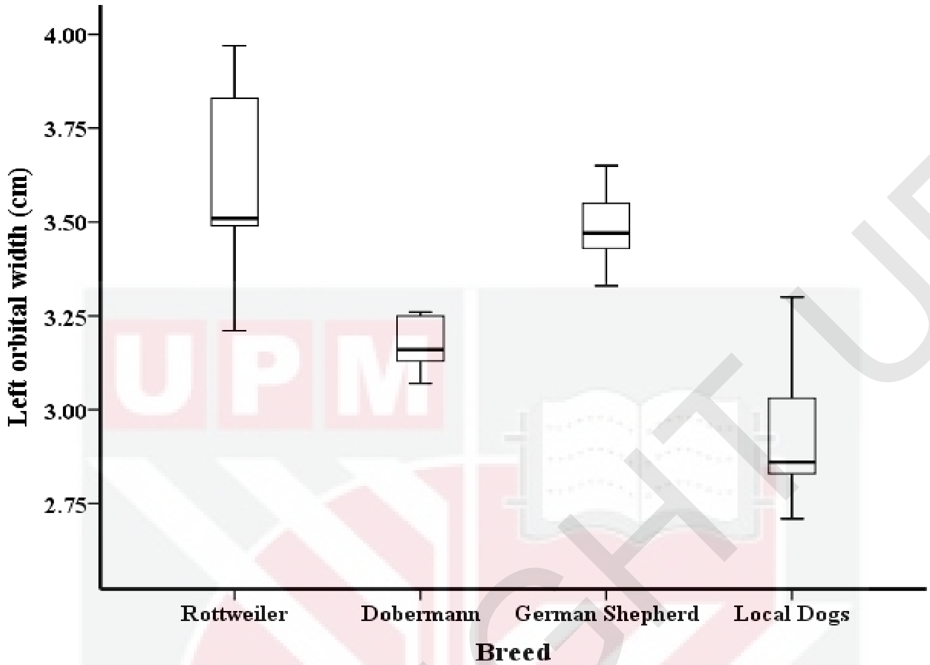

Figure 13: Box-plots of left orbital width in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 6: Summary on the p value of left orbital width in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.019	0.802	0.001
Dobermann			0.110	0.318
German Shepherd				0.001

4.1.8 Correlation between the Right and Left Orbital widths

The right orbital width was found out to be positively correlated with the left orbital widths with statistical significance (Figure 14). The results suggest that there is symmetry between the left and right orbital widths across all the breeds.

Correlations

		Right orbital width	Left orbital width
Right orbital width	Pearson Correlation	1	.976**
	Sig. (2-tailed)		.000
	N	20	20
Left orbital width	Pearson Correlation	.976**	1
	Sig. (2-tailed)	.000	
	N	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 14: Summary of correlations between right orbital width and left orbital width

4.2 Skull Lateral View

4.2.1 Height measuring from Occipital lobe till floor of Mandible

At $\alpha = 0.05$, Rottweiler showed no significant differences in measurements of height from the occipital lobe to the floor of mandible as compared with the Dobermann, however, it was found that the height was significantly taller in the German Shepherd compared to all other breeds (Figure 15 and Table 7). Local dogs are significantly shorter compared to the other three breeds (Figure 15 and Table 7).

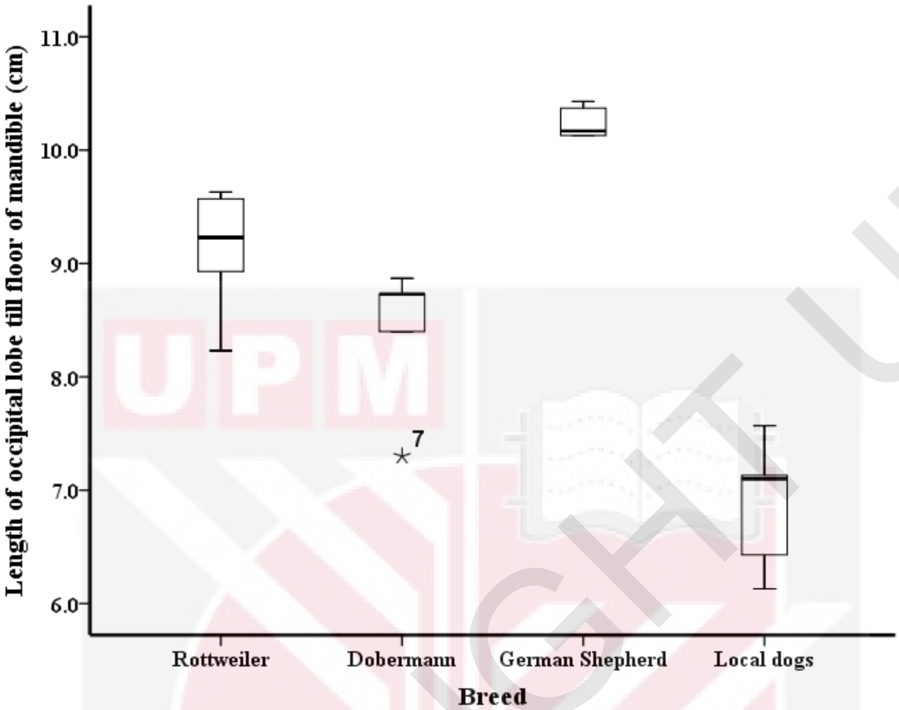

Figure 15: Box-plots of length measuring from occipital lobe till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk is outlier.

Table 7: Summary on the p value of length measuring from occipital lobe till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.180	0.017	<0.0001
Dobermann			0.000	<0.0001
German Shepherd				<0.0001

4.2.2 Height measuring from Most Dorsal Coronal Suture till floor of Mandible

At α = 0.05, there was no significant differences among Rottweiler, Dobermann and Geman Shepherd (Figure 16 and Table 8). On contrary, local dogs were significantly shorter in terms of length from the most coronal suture to the floor of the mandible as compared to other three breeds.

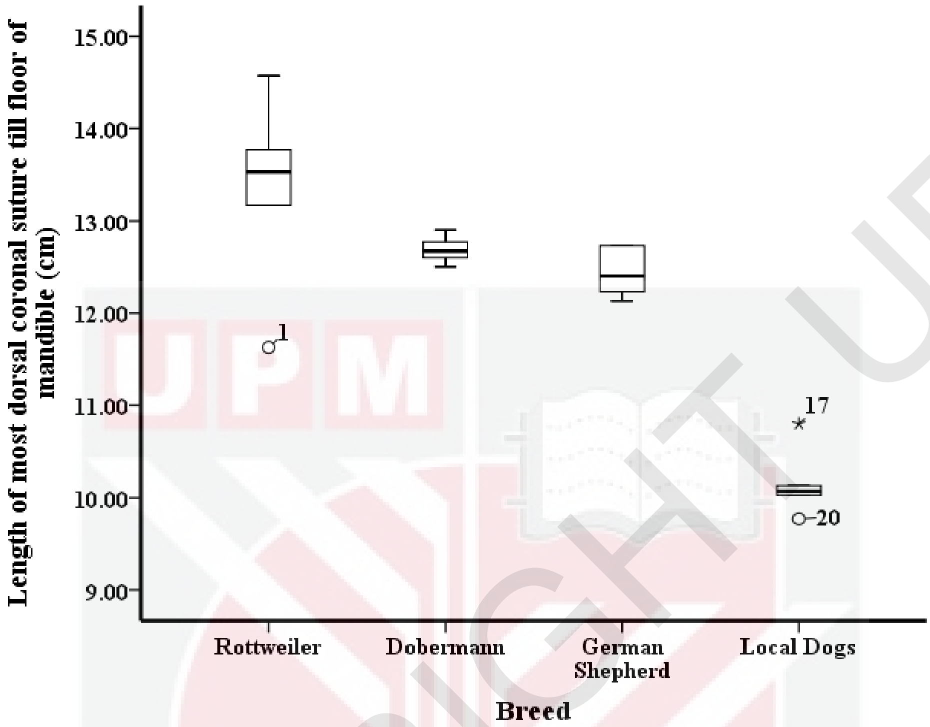

Figure 16: Box-plots of length measuring from most dorsal coronal suture till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 8: Summary on the p value of length measuring from occipital lobe till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.349	0.125	<0.0001
Dobermann			0.915	<0.0001
German Shepherd				<0.0001

4.2.3 Height measuring from Nasal Frontal till floor of Maxilla

At α = 0.05, there was no significant differences among the Rottweiler, Dobermann and German Shepherd (Figure 17 and Table 9). However, local dogs was measured with significantly shorter height of the nasal frontal till the floor of maxilla as compared to the other three breeds (Figure 17 and Table 9).

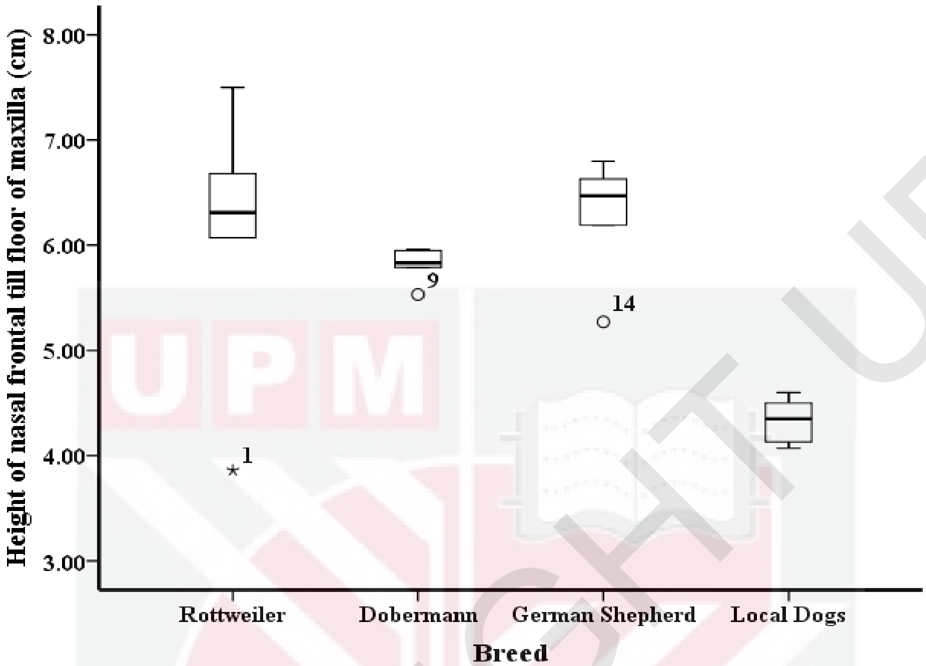

Figure 17: Box-plots of height measuring from nasal frontal till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 9: Summary on the p value of length measuring from nasal frontal till floor of mandible in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.940	0.979	0.010
Dobermann			0.772	0.031
German Shepherd				0.005

4.2.4 Height measuring from Nasal Tip till floor of Maxilla

At α = 0.05, there were no significant differences among Rottweiler, Dobermann and German Shepherd (Figure 18 and Table 10). The local dogs revealed with a significantly shorter height from the the nasal tip to the floor of maxilla compared to other three breeds (Figure 18 and Table 10). Dog numbered 5, 13 and 17 are significantly larger than their respective breed group.

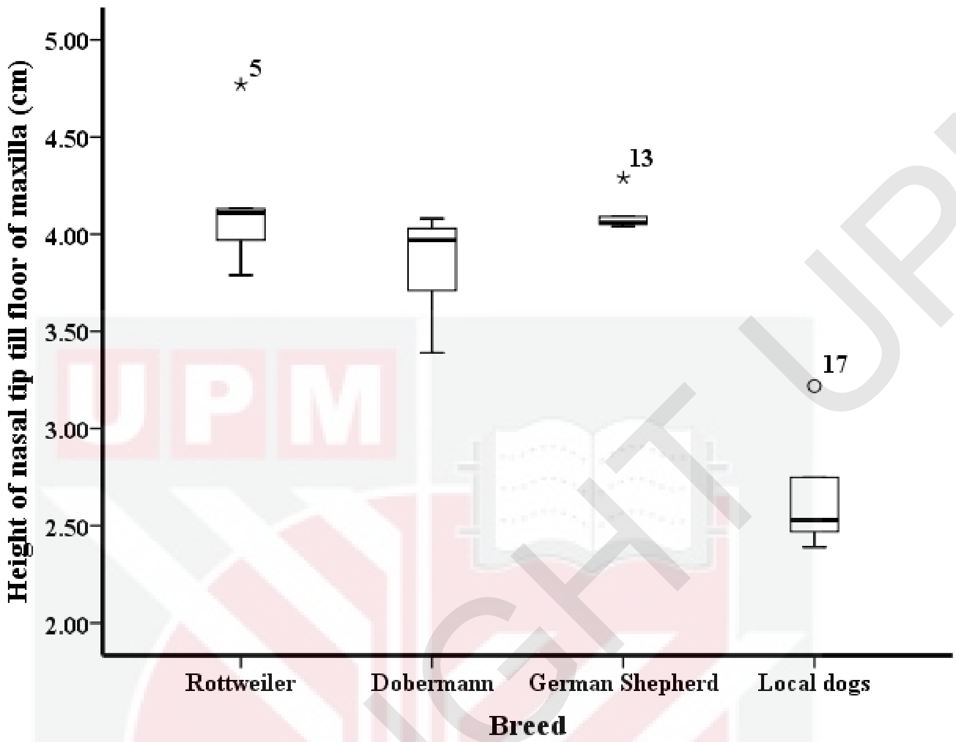

Figure 18: Box-plots of heights measuring from the nasal tip till floor of maxilla in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 10: Summary on the p value of lengths measuring from nasal tip till floor of maxilla in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.347	0.979	<0.0001
Dobermann			0.772	<0.0001
German Shepherd				<0.0001

4.2.5 Length of Maxilla

At $\alpha = 0.05$, there were no significant differences between the length of the maxilla between the Dobermann and German Shepherd, while Rottweiler's measurement was significantly shorter compared to both Dobermann and German Shepherd. Local dogs once again was found to have significantly shorter length of maxilla compared to others (Figure 19 and Table 11).

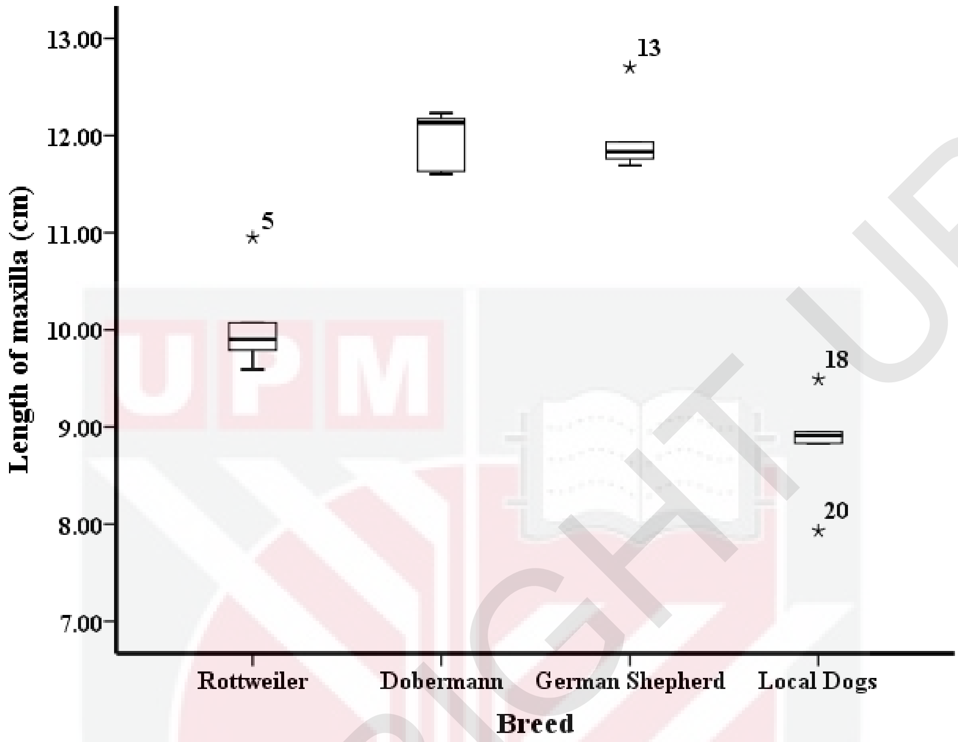

Figure 19: Box-plots of length of maxilla in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 11: Summary on the p value of length of maxilla in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.000	0.000	0.003
Dobermann			1.000	<0.0001
German Shepherd				<0.0001

4.2.6 Length of Mandible

At α = 0.05, there was no significant differences between the Rottweiler, Dobermann and German Shepherd on length of mandible however the local dogs were found to have significantly shorter mandible (Figure 20 and Table 12).

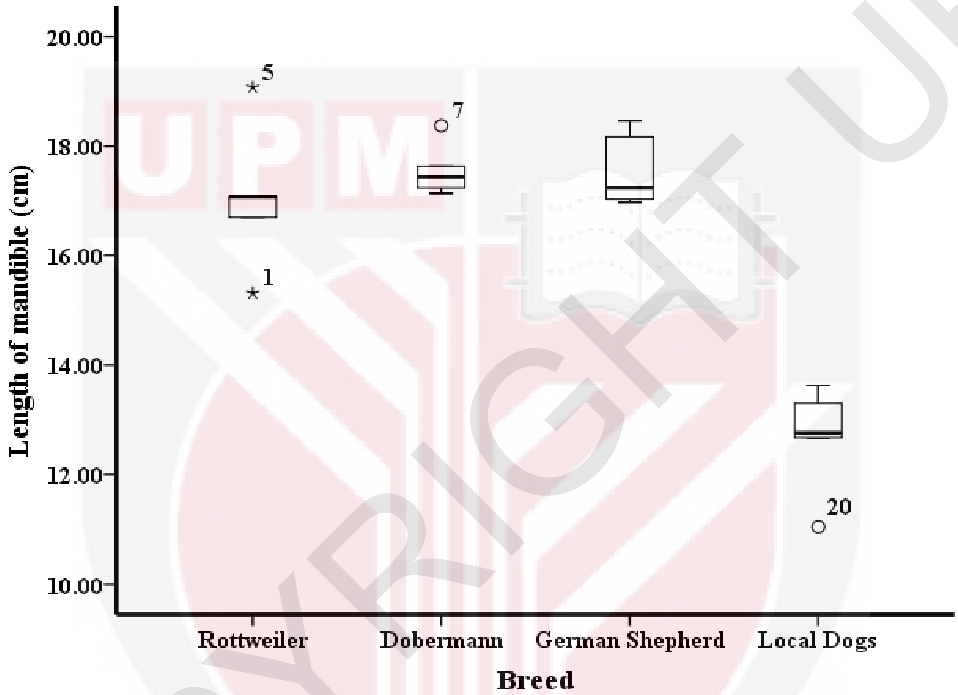

Figure 20: Box-plots of length of mandible in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers

Table 12: Summary on the p value of length of mandible in Rottweiler, Dobermann, German Shepherd and local dogs

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.821	0.810	<0.0001
Dobermann			1.000	<0.0001
German Shepherd				<0.0001

4.3 Dentition Measurement

4.3.1 Maxilla

At $\alpha = 0.05$, Rottweiler's maxilla showed no significant differences on all measurements compared to Dobermann and German Shepherd except the distance measuring from right third premolar to left third premolar ($p < 0.0001$) and the distance measuring from right fourth premolar to left fourth premolar ($p < 0.0001$). There are no significant differences between Dobermann and German Shepherd. Maxilla of local dogs showed significant differences ($p < 0.0001$) from other three breeds, except the distance measuring from second right premolar to second left premolar comparing to Dobermann and German Shepherd.

4.3.2 Mandible

At $\alpha = 0.05$, Rottweiler's mandible showed no significant differences on all measurements compared to Dobermann and German Shepherd except the distance measuring from right third premolar to left third premolar ($p < 0.0001$) and the distance measuring from right fourth premolar to left fourth premolar ($p < 0.0001$) . There are no significant differences between Dobermann and German Shepherd. Mandible of local dogs showed significant differences ($p < 0.0001$) from other three breeds, except the distance measuring from second right premolar to second left premolar comparing to Dobermann and German Shepherd.

4.4 Biting Force

4.4.1 Canine Biting Force (CBF)

At α = 0.05, there was no significant differences in biting forces comparing the Rottweiler with the Dobermann; however, there was significant higher biting force in the Rottweiler compared to the German Shepherd (Figure 21 & Table 13) similarly to the Dobermann as well. The local dogs have significantly lowest Canine biting forces when compared to all other breeds (Figure 21 & Table 13).

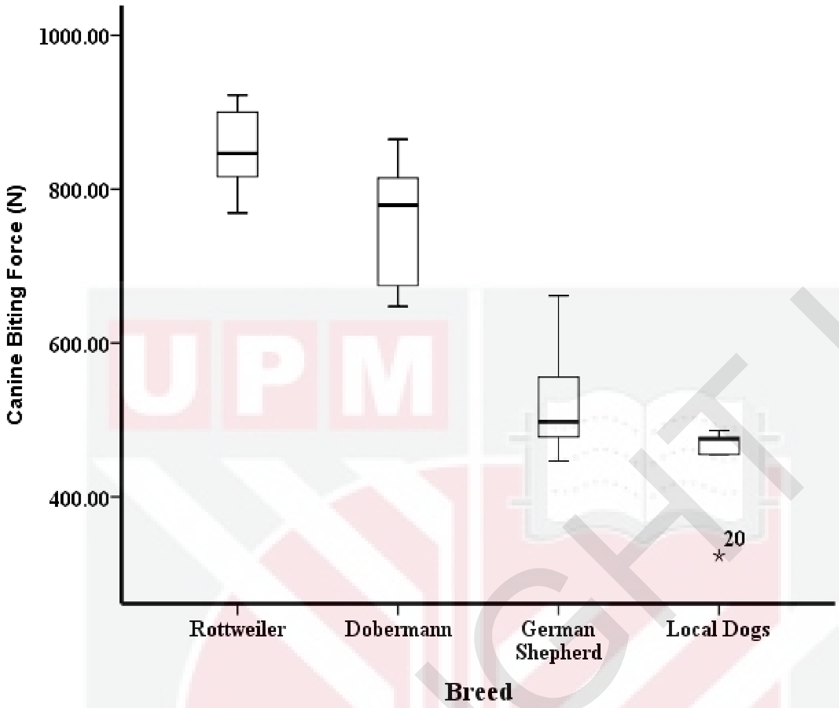

Figure 21: Boxplots of canine biting force in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk is outlier.

Table 13: Summary on the p value of total length of skull on the multiple comparison among the breeds

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.257	0.000	<0.0001
Dobermann			0.001	<0.0001
German Shepherd				0.347

4.4.2 Molar Biting Force (MBF)

At α = 0.05, the molar biting forces of Rottweiler have no significant differences from Dobermann and German Shepherd (Figure 22 & Table 14). However, there are significant differences in Dobermann and German Shepherd's biting forces (Figure 22 & Table 14). In contrast, local dogs have significant lowest Molar biting forces compared to all other three breeds (Figure 22 & Table 14).

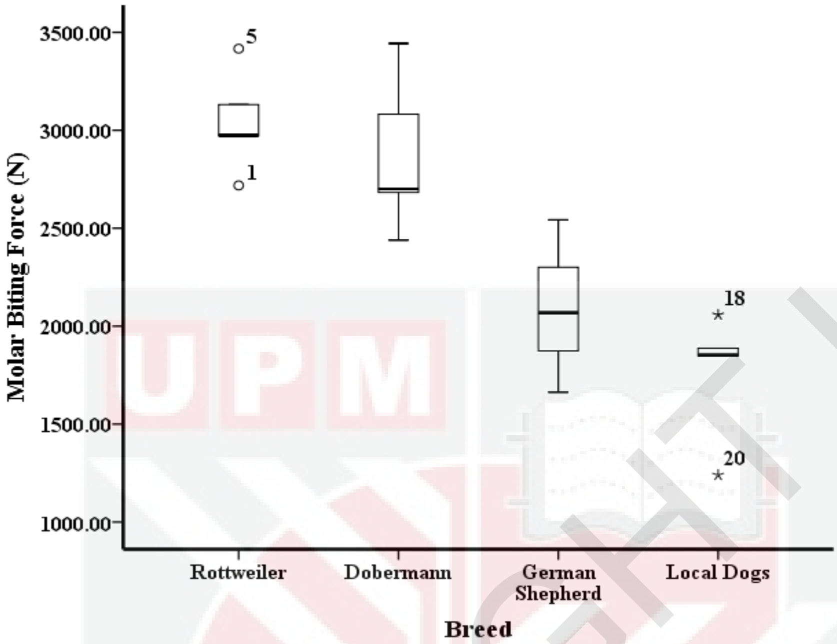

Figure 22: Box-plots of molar biting force in Rottweiler, Dobermann, German Shepherd and local dogs. Asterisk and circle are outliers.

Table 14: Summary on the p value of total length of skull on the multiple comparison among the breeds

	Rottweiler	**Dobermann**	**German Shepherd**	**Local Dogs**
Rottweiler		0.842	0.002	<0.0001
Dobermann			0.009	<0.0001
German Shepherd				0.465

4.4.3 Skull Length with CBF

At α = 0.05, there is significant correlation between skull length and canine biting force; however, they are moderately correlated (Table 15).

Table 15: Summary of correlations between skull length and canine biting force

Correlations

		Skull Length	**Canine Biting Force**
Skull Length	**Pearson Correlation**	1	0.474**
	Sig. (2 tailed)		0.035
	N	20	20
Canine Biting Force	**Pearson Correlation**	0.474**	1
	Sig. (2 tailed)	0.035	
	N	20	20

**** Correlation is significant at the level 0.05 level (2 tailed).**

4.4.4 Zygomatic Width with CBF

At α = 0.01, there was a positive and significant correlation between the zygomatic width and canine biting force, with the skull length (Table 16).

Table 16: Summary of correlations between zygomatic width and canine biting force

Correlations

		Zygomatic Width	**Canine Biting Force**
Zygomatic width	**Pearson Correlation**	1	0.703**
	Sig. (2 tailed)		0.001
	N	20	20
Canine Biting Force	**Pearson Correlation**	0.703**	1
	Sig. (2 tailed)	0.001	
	N	20	20

**** Correlation is significant at the level 0.01 level (2 tailed).**

4.4.5 Skull Length with MBF

At α = 0.05, there was a positive correlation between skull length and molar biting force; however, they are moderately correlated (Table 17).

Table 17: Summary of correlations between skull length and molar biting force

Correlations

		Zygomatic Width	**Canine Biting Force**
Zygomatic width	**Pearson Correlation**	1	0.511**
	Sig. (2 tailed)		0.021
	N	20	20
Canine Biting Force	**Pearson Correlation**	0.511**	1
	Sig. (2 tailed)	0.021	
	N	20	20

**** Correlation is significant at the level 0.01 level (2 tailed).**

4.4.6 Zygomatic Width with MBF

At α = 0.01, there was a positive correlation between zygomatic width and molar biting force, and they are more highly correlated compared to skull length (Table 18).

Table 18: Summary on correlations between zygomatic width and molar biting force

Correlations

		Zygomatic Width	**Canine Biting Force**
Zygomatic width	**Pearson Correlation**	1	0.654**
	Sig. (2 tailed)		0.002
	N	20	20
Canine Biting Force	**Pearson Correlation**	0.654**	1
	Sig. (2 tailed)	0.002	
	N	20	20

**** Correlation is significant at the level 0.01 level (2 tailed).**

5.0 DISCUSSION

The use of comparative anatomy in forensic investigation in identifying the offending dog in the assault is crucial. Dogs have had involved in fatal attacks and death, hence by looking and comparing the available dentition may actually lead us to the potential offending dog. There were no studies being done in Malaysia in comparing local dogs to other breed of dogs in terms of skull dimensions, dentition and biting forces.

By referring to skull index recommended by Miller and co-researchers in the year 1965, the mean values for skull indexes for Brachycephalic skulls are 81%, Mesaticephalic 52% and Dolicocephalic 39%. The present study revealed that Rottweiler was classified as Mesaticephalic dog with a mean total length of skull of 51%, while both Dobermann and German Shepherd has a mean value of 39%, which further group them as Dolicocephalic. As for local dogs, the mean for their skulls are 45% which makes them falls between the Dolicocephalic and Mesaticephalic dogs. Among all skull dimensions, there were no significant differences between Dobermann and German Shepherd. These were the total length of skull, length measuring from caudal end to nasal end, lacrimal width, zygomatic width, right and left orbital width for the dorsal view of the skull; and height measuring from the occipital lobe till floor of mandible, height measuring from coronal suture till floor of mandible, height measuring from nasal frontal till floor of maxilla, height measuring from nasal tip till floor of maxilla, length of maxilla and length of mandible. The lack of significant differences in the dimensions could be because

Dobermann and German Shepherd are both having the same skull index indicating both breeds are having almost the same skull dimensions. Local dogs' skulls are smaller than other three breeds, making their skull dimensions significantly shorter from other three breeds.

Relationship exist between skull shape and biting forces, and differencesin biting forces caused by skull shape are more evident in Mesaticephalic skulls than in Dolicocephalic skulls as seen in this study. High variability can be known as the consequences of the breeders outcross their pure breeds to avoid deleterious effects due to high levels of inbreeding or to eradicate specific genetic defects (Ubbink, Knol & Bouw, 1992). By comparing to the study done by Ellis and co-researchers in 2009, the present study showed that there was an increment in the biting forces as the skull size increases. Biting forces in small Brachycephalic dog such as Chihuahua is weak as their calvaria is disproportionate in relation to facial structure; a larger brain case limit the space available for the masseter muscles to occupy, and thus the limited muscle size contribute to lower biting forces which is not in agreement with the studies done by Ellis and company in 2009. Biting forces for Dolicocephalic dogs are much lower even though they have a bigger calvarium compared to small breed dogs, this could be due to the long-out lever arm counteract the biting forces making the biting forces (Ellis *et al.*, 2009) for Dolicocephalic significantly different from Mesaticephalic dogs.

The biting forces in this study were estimated by measuring the defleshed dried skulls and calculated using the equation adapted from Kiltie, 1984. All the calculated forces are just estimation by measuring the dried skulls which does not take into account the different forces that could possibly exerted on both sides of the head. Gans, Gorniak and Morgan in 1990 indicated that bite forces generated during chewing are depending on many other factors including the texture of the food and the muscles recruitment for a particular activity for the oral cavity as not all muscles are involved in mastication. This will affects the dry skull results as there are other confounding factors affecting the biting forces.

Future studies should include more local dogs in finding their skull dimensions, dentition and biting forces to aid in investigation and crime. Comparison between local dogs and brachycephalic dogs can be made as this was not done in this study. Other than that, non invasive methods such as Computerized tomography (CT) scan and radiography can also be used to aid in the investigation as well.

6.0 CONCLUSION

Each breed has their own distinct skull dimension, dentition and biting forces. Local dogs are significantly smaller from other three breeds in terms of skull dimensions dentition and biting forces. Rotweiller has the highest biting forces compared to other breeds while the Malaysian local dogs have the lowest. Zygomatic width plays a significant role in determining both canine and molar biting forces in domestic dogs.

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APPENDICES

Appendix A : Measurements of the skull (Dorsal View)																		
Species	**Total length**			**Length measuring from the caudal end to the nasal end**			**Lacrimal width**			**Zygomatic width**			**Orbital diameter (Right)**			**Orbital diameter (Left)**		
R1	24.30	24.00	23.90	20.00	20.10	20.20	4.72	4.72	4.80	11.56	11.56	11.56	3.52	3.52	3.51	3.50	3.51	3.52
R2	25.20	25.00	25.10	21.80	21.50	21.60	6.16	6.25	6.10	12.80	12.85	12.80	3.80	4.00	4.05	4.00	4.00	3.90
R3	24.90	24.50	24.40	22.10	22.00	22.20	5.00	5.10	5.06	11.58	11.58	11.50	3.50	3.54	3.50	3.50	3.50	3.48
R4	25.40	25.20	25.30	22.90	22.80	23.00	6.04	5.98	6.00	13.10	13.18	13.20	3.30	3.24	3.14	3.20	3.20	3.24
R5	26.00	26.00	26.20	24.00	23.90	23.90	6.40	6.10	6.14	14.74	14.70	14.80	3.90	3.78	3.94	3.80	3.80	3.90
D1	29.50	29.60	29.60	25.80	26.10	25.80	5.58	5.80	5.70	11.40	11.50	11.50	3.20	3.10	3.27	3.18	3.10	3.20
D2	28.50	28.40	28.20	24.00	23.90	24.10	5.48	5.50	5.50	11.10	11.20	11.24	3.20	3.10	3.10	3.20	3.10	3.10
D3	28.00	28.10	28.10	24.00	23.90	24.10	4.98	4.80	4.88	10.80	10.60	10.70	3.30	3.20	3.38	3.20	3.30	3.28
D4	27.30	27.10	27.10	23.00	22.50	23.00	5.20	5.29	5.20	10.80	10.84	10.84	3.10	3.10	3.18	3.10	3.10	3.00
D5	27.50	27.40	27.40	23.50	23.40	23.30	5.30	5.40	5.50	11.70	11.80	11.70	3.24	3.30	3.28	3.30	3.20	3.24
G1	27.20	27.20	27.10	22.20	22.20	22.10	5.54	5.60	5.68	11.80	11.80	11.70	3.40	3.48	3.40	3.70	3.70	3.70
G2	28.10	28.00	28.00	22.10	22.00	22.00	5.40	5.50	5.50	11.10	11.08	11.08	3.50	3.50	3.40	3.50	3.60	3.50
G3	30.10	30.20	30.10	24.20	24.30	24.20	5.14	5.30	5.20	11.90	11.98	11.90	3.70	3.74	3.70	3.80	3.84	3.78
G4	29.80	29.90	29.80	22.80	22.90	22.80	5.10	5.20	5.10	10.40	10.20	10.38	3.20	3.30	3.20	3.30	3.30	3.40
G5	28.20	28.10	28.00	22.20	22.00	22.40	5.44	5.50	5.50	11.00	11.00	11.10	3.60	3.58	3.54	3.50	3.54	3.60
M1	19.80	20.10	19.70	17.30	17.00	17.20	3.90	3.90	3.90	8.90	9.00	9.00	2.90	2.80	2.84	2.80	2.88	2.90
M2	22.30	22.20	22.20	18.10	18.80	18.30	4.00	4.10	4.00	10.40	10.50	10.40	3.20	3.40	3.38	3.40	3.30	3.20
M3	21.00	21.00	21.20	18.20	18.10	18.30	4.00	4.10	4.00	8.60	8.60	8.58	2.70	2.74	2.74	2.70	2.70	2.74
M4	21.20	21.00	21.00	18.10	18.00	18.10	4.20	4.30	4.20	9.50	9.40	9.48	3.10	3.10	3.10	3.00	3.10	3.00
M5	18.20	18.40	18.10	15.60	15.80	15.80	3.80	3.84	3.80	8.50	8.50	8.50	2.80	2.80	2.80	2.80	2.80	2.90

Appendix B : Measurements of the skull (Lateral View)

Species	Length of occipital lobe till floor of mandible			Length of most dorsal coronal suture till floor of mandible			Height of nasal frontal till floor of maxilla			Height of nasal tip till floor of maxilla			Length of maxilla			Length of mandible		
R1	8.20	8.00	8.50	11.60	11.70	11.60	3.90	3.84	3.84	3.90	3.78	3.70	9.55	9.53	9.70	15.30	15.31	15.31
R2	9.50	9.60	9.80	13.40	13.50	13.70	6.34	6.30	6.30	4.10	4.10	4.20	9.70	9.78	9.90	17.00	17.10	17.10
R3	9.20	8.60	9.00	13.30	13.20	13.00	6.20	5.90	6.10	3.98	3.99	3.93	10.10	9.90	10.20	17.00	17.10	17.10
R4	9.50	9.50	9.70	13.80	13.90	13.60	6.70	6.74	6.60	4.10	4.10	4.14	10.00	9.80	9.90	16.80	16.60	16.70
R5	9.20	9.00	9.50	14.80	14.30	14.60	7.50	7.50	7.50	4.80	4.80	4.70	10.90	11.00	10.94	19.20	19.10	18.90
D1	7.20	7.40	7.30	12.80	12.60	12.40	5.80	5.90	6.18	3.44	3.34	3.40	11.60	11.65	11.55	17.60	17.70	17.60
D2	8.40	8.40	8.40	12.40	12.70	12.40	5.98	5.99	5.88	4.00	4.00	4.08	12.20	12.20	12.30	18.40	18.30	18.40
D3	8.70	8.90	8.60	12.90	12.80	13.00	5.90	5.74	5.74	3.70	3.74	3.70	12.10	12.20	12.20	17.20	17.10	17.10
D4	8.80	9.00	8.80	12.60	12.80	12.90	5.50	5.50	5.60	4.08	4.08	4.08	12.10	12.10	12.18	17.20	17.30	17.20
D5	8.70	8.80	8.70	12.60	12.80	12.60	5.88	5.70	5.90	3.94	3.98	4.00	11.68	11.60	11.60	17.48	17.40	17.45
G1	10.10	10.20	10.10	12.80	12.80	12.60	6.70	6.90	6.80	4.00	4.08	4.05	11.90	11.90	12.00	18.20	18.20	18.10
G2	10.20	10.20	10.10	12.20	12.30	12.20	6.60	6.60	6.70	4.00	4.08	4.08	11.80	11.90	11.78	17.10	17.00	17.00
G3	10.50	10.30	10.50	12.80	12.60	12.80	6.18	6.20	6.18	4.38	4.30	4.18	12.70	12.70	12.70	18.40	18.48	18.50
G4	10.30	10.30	10.50	12.50	12.30	12.40	5.20	5.40	5.20	4.00	4.10	4.18	11.70	11.68	11.70	17.20	17.30	17.20
G5	10.10	10.10	10.20	12.10	12.20	12.10	6.50	6.40	6.50	4.00	4.10	4.08	11.70	11.80	11.78	17.00	16.90	17.00
M1	7.10	7.20	7.00	10.00	10.20	10.00	4.50	4.50	4.50	2.40	2.60	2.60	8.94	8.90	8.90	12.70	12.70	12.60
M2	7.10	7.20	7.10	10.90	10.80	10.70	4.50	4.70	4.60	3.28	3.20	3.18	8.80	8.78	8.90	13.60	13.68	13.60
M3	6.10	6.10	6.20	10.20	10.00	10.20	4.10	4.18	4.10	2.40	2.50	2.50	9.50	9.50	9.48	13.30	13.40	13.20
M4	7.50	7.60	7.60	10.00	10.10	10.00	4.30	4.34	4.40	2.38	2.40	2.40	9.00	8.90	8.94	12.78	12.70	12.80
M5	6.30	6.50	6.50	9.70	9.80	9.80	4.00	4.10	4.10	2.70	2.78	2.78	7.90	4.90	8.00	11.00	11.04	11.08

Appendix C: Measurement of Teeth (Maxilla view)

Species	Length from RI3 till LI3			Length from RC1 till LC1			Length from RPM1 till LPM1			Length from RPM2 till LPM2			Length from RPM3 till LPM3			Length from RPM4 till LPM4			Length from RM1 till LM1			Length from RM2 till LM2		
R1	3.20	3.20	3.20	4.60	4.60	4.70	4.10	4.16	4.10	4.59	4.50	4.46	5.50	5.50	5.50	6.75	6.90	6.90	6.70	6.70	6.70	5.77	5.80	5.77
R2	3.50	3.40	3.80	5.00	5.30	5.30	4.55	4.55	4.55	4.55	4.55	4.55	5.50	5.50	5.50	7.50	7.50	7.50	7.08	7.08	7.00	6.00	5.94	5.94
R3	3.48	3.46	3.40	4.70	4.80	4.80	4.38	4.36	4.35	4.76	4.67	4.68	5.64	5.80	5.74	7.50	7.40	7.50	6.90	7.20	7.20	5.80	5.80	5.90
R4	3.60	3.70	3.60	5.50	5.44	5.40	4.60	4.60	4.64	5.10	5.10	5.14	6.90	6.90	6.90	8.10	8.10	8.20	7.30	7.30	7.30	6.10	6.14	6.04
R5	4.44	4.40	4.46	6.50	6.44	6.50	5.06	5.10	5.04	7.10	7.10	7.14	7.10	7.10	7.10	8.40	8.40	8.34	7.90	7.94	7.94	6.90	6.70	6.70
D1	3.50	3.50	3.50	4.30	4.32	4.30	3.90	4.00	4.00	3.80	4.24	4.20	5.38	5.10	5.00	6.84	6.84	6.90	6.80	6.90	6.90	5.94	6.00	5.90
D2	4.08	4.00	4.04	5.00	5.00	5.00	4.83	4.80	4.80	4.90	4.90	4.90	5.60	5.60	5.64	7.10	7.10	7.17	6.90	6.90	6.87	6.10	6.10	6.10
D3	3.68	3.68	3.50	4.40	4.40	4.40	3.90	3.90	3.90	4.10	4.10	4.10	4.90	5.04	4.90	6.60	6.60	6.64	6.30	6.42	6.40	5.80	5.80	5.70
D4	3.68	3.68	3.70	4.90	4.90	5.00	4.08	4.04	4.00	4.20	4.20	4.20	5.04	5.10	5.00	6.50	6.50	6.50	6.28	6.30	6.30	5.60	5.58	5.60
D5	3.90	3.90	3.90	4.40	4.90	4.90	4.30	4.48	4.40	4.40	4.38	4.34	5.40	5.40	5.40	6.90	7.00	7.00	6.78	6.70	6.74	6.40	6.34	6.34
G1	3.80	3.98	3.80	5.08	5.00	5.04	4.04	4.08	3.98	4.30	4.24	4.30	5.30	5.28	5.30	7.08	6.98	6.94	7.30	7.28	7.30	6.30	6.30	6.30
G2	3.70	3.70	3.70	4.60	4.60	4.60	4.08	4.10	4.10	4.30	4.38	4.30	5.18	5.30	5.34	6.90	6.94	7.00	6.90	6.90	6.90	6.00	5.90	6.00
G3	3.70	3.70	3.70	4.90	4.90	5.00	4.20	4.18	4.24	4.30	4.40	4.50	5.60	5.54	5.50	7.00	7.00	7.08	6.70	6.80	6.80	6.30	6.30	6.20
G4	3.30	3.20	3.30	4.40	4.44	4.48	3.80	3.80	3.80	3.90	3.90	3.90	4.80	4.80	4.90	6.40	6.40	6.40	6.60	6.60	6.74	6.40	6.30	6.40
G5	3.70	3.64	3.70	4,58	4,60	4.60	4.10	4.10	4.10	4.40	4.30	4.40	5.20	5.18	5.18	6.80	6.90	6.90	6.70	6.70	6.78	5.90	5.80	6.00
M1	3.00	3.00	3.00	3.50	3.40	3.40	3.20	3.10	3.20	3.34	3.40	3.30	4.14	4.10	4.20	5.58	5.60	5.40	5.60	5.60	5.50	5.00	5.00	5.10
M2	3.10	3.00	3.10	3.90	3.80	3.88	3.44	3.40	3.50	3.70	3.70	3.68	4.50	4.50	4.50	6.00	6.10	6.00	5.84	5.88	5.80	5.20	5.20	5.20
M3	2.74	2.74	2.78	3.46	3.48	3.48	3.00	3.00	3.00	3.30	3.30	3.30	4.08	4.10	4.10	5.60	5.60	5.60	5.50	5.50	5.60	5.00	5.00	5.00
M4	2.60	2.60	2.70	3.60	3.60	3.60	3.10	3.10	3.10	3.28	3.28	3.30	4.00	4.04	4.10	5.44	5.50	5.50	5.80	5.90	5.80	4.80	4.80	4.84
M5	2.70	2.70	2.70	3.40	3.40	3.40	3.08	3.10	3.08	3.20	3.20	3.28	3.90	3.94	3.90	5.20	5.20	5.20	5.30	5.34	5.40	4.84	4.88	4.90

Legend for Table 3 & Table 4:

RI	Right incisor	RPM	Right premolar
LI	Left incisor	LPM	Left premolar
RC	Right canine	RM	Right molar
LC	Left canine	LM	Left molar

Appendix D: Measurement of Teeth (Mandible view)

Species	Length from RI3 till LI3			Length from RC1 till LC1			Length from RPM1 till LPM1			Length from RPM2 till LPM2			Length from RPM3 till LPM3			Length from RPM4 till LPM4			Length from RM1 till LM1			Length from RM2 till LM2			Length from RM3 till LM3		
R1	2.84	2.80	2.74	4.14	4.20	4.04	2.40	2.39	2.40	3.40	3.30	3.30	4.44	4.30	4.44	5.30	5.28	5.20	5.54	5.55	5.60	5.45	5.40	5.34	4.68	4.60	4.65
R2	3.00	3.10	3.10	4.60	4.40	4.70	2.72	2.80	2.73	3.80	3.78	3.80	4.90	4.84	4.90	5.94	5.94	5.90	5.90	5.90	5.90	5.90	5.90	5.80	4.50	4.55	4.60
R3	2.84	2.80	2.82	4.08	4.08	4.00	2.54	2.50	2.54	3.50	3.50	3.45	4.60	4.70	4.70	5.78	5.84	5.80	6.00	5.94	5.90	5.80	5.68	5.68	4.60	4.65	4.70
R4	2.90	2.94	2.94	4.30	4.38	4.30	4.06	4.08	4.08	4.90	5.00	4.98	6.20	6.20	6.20	6.40	6.44	6.50	6.10	6.10	6.20	5.70	5.80	5.70	4.40	4.40	4.45
R5	3.80	3.80	3.84	5.04	5.08	5.08	4.30	4.30	4.30	5.40	5.40	5.40	6.50	6.46	6.46	6.60	6.10	6.04	6.10	6.10	6.04	5.68	5.68	5.80	4.50	4.50	4.50
D1	2.60	2.60	2.60	3.84	3.94	3.90	2.74	2.70	2.80	3.60	3.74	3.60	4.40	4.30	4.40	4.94	4.90	4.94	5.44	5.50	5.39	5.20	5.20	5.20	4.90	4.94	4.98
D2	3.44	3.40	3.40	4.20	4.20	4.30	3.30	3.30	3.30	4.06	4.00	4.04	4.60	4.66	4.60	5.28	5.30	5.30	5.70	5.60	5.70	5.30	5.28	5.40	5.00	5.00	5.00
D3	2.60	2.70	2.70	3.90	3.90	3.90	2.40	2.40	2.40	3.10	3.10	3.10	4.10	4.08	4.08	5.00	5.08	4.94	5.10	5.00	5.18	4.94	4.80	4.74	4.60	4.50	4.70
D4	2.90	2.90	2.90	4.04	4.11	4.10	2.64	2.68	2.60	3.20	3.20	3.10	4.04	4.04	4.04	4.80	4.80	4.80	5.10	5.10	5.10	4.94	4.98	4.90	4.50	4.50	4.50
D5	3.30	3.20	3.18	4.50	4.50	4.60	2.80	2.80	2.80	3.50	3.50	3.50	4.30	4.30	4.20	5.10	5.10	5.18	5.50	5.50	5.48	5.50	5.50	5.58	5.28	5.28	5.30
G1	3.10	3.00	3.10	4.70	4.68	4.70	3.00	3.00	3.00	3.38	3.38	3.40	4.10	4.10	4.08	5.00	5.00	5.00	5.50	5.54	5.50	5.40	5.40	5.30	5.08	5.00	5.00
G2	3.00	3.00	2.98	4.40	4.40	4.40	2.50	2.58	2.60	2.90	3.10	3.10	4.18	4.30	4.20	5.20	5.18	5.10	5.50	5.50	5.50	5.20	5.20	5.30	4.80	4.90	4.88
G3	3.40	3.48	3.40	3.70	3.70	3.70	2.80	2.88	2.90	3.40	3.40	3.40	4.20	4.20	4.20	4.90	5.00	4.90	5.60	5.58	5.60	5.40	5.38	5.38	5.00	5.00	5.08
G4	2.80	2.80	2.78	4.00	4.00	4.00	2.60	2.70	2.60	2.80	2.84	2.84	3.44	3.50	3.60	4.80	4.80	4.80	5.08	5.10	5.10	4.90	4.90	4.80	4.70	4.60	4.74
G5	3.00	3.00	2.94	4.30	4.40	4.30	2.60	2.58	2.50	2.88	3.00	3.00	4.00	4.20	4.20	5.00	5.10	5.20	5.50	5.50	5.50	5.20	5.10	5.20	4.70	4.80	4.60
M1	2.20	2.18	2.18	3.00	3.04	3.00	2.00	2.00	2.00	2.38	2.30	2.30	3.00	3.00	2.98	3.60	3.70	3.70	4.10	4.20	4.17	4.30	4.20	4.40	4.40	4.40	4.40

M2	2.34	3.30	2.30	3.40	3.40	3.44	2.24	2.28	2.30	2.78	2.78	2.78	3.50	3.50	3.50	4.20	4.20	4.20	4.70	4.74	4.78	4.70	4.78	4.74	4.45	4.43	4.40
M3	1.80	1.90	1.80	3.04	3.10	3.10	2.00	2.00	2.00	2.44	2.50	2.40	3.10	3.20	3.14	3.84	3.90	3.90	3.90	3.90	3.90	4.10	4.14	4.10	4.58	4.60	4.58
M4	2.20	2.20	2.30	3.50	3.50	3.40	2.20	2.20	2.30	2.90	2.90	2.90	3.50	3.50	3.60	4.08	4.14	4.14	4.60	4.60	4.60	4.60	4.60	4.60	4.70	4.70	4.80
M5	2.20	2.20	2.18	3.00	3.00	3.08	2.18	2.18	2.20	2.40	2.35	2.40	2.40	2.40	2.38	3.00	3.00	3.00	3.70	3.80	3.60	4.60	4.68	4.60	4.60	4.60	4.60

Appendix E: Measurements of Canine Biting Forces (CBF) and Molar Biting Forces (MBF)

Species	Lm			M			Lm x M			Lt			T			Lt x T			Oc			Om			CBF	MBF
R1	7.60	7.80	7.90	7.20	7.30	7.50	54.72	56.94	59.25	3.60	3.80	3.70	38.43	37.84	37.40	138.35	143.79	138.38	13.80	13.70	13.80	7.40	7.50	7.40	768.85	2718.39
R2	7.74	8.00	7.90	7.15	7.55	7.67	55.34	60.40	60.59	3.10	3.10	3.10	49.19	49.00	49.49	152.49	151.90	153.42	13.90	13.90	13.90	7.20	7.30	7.40	816.14	2973.97
R3	8.00	8.10	8.20	7.40	7.55	7.07	59.20	61.16	57.97	4.10	4.18	4.30	39.78	38.76	39.39	163.10	162.02	169.38	13.30	13.40	13.40	7.30	7.40	7.40	900.25	3130.97
R4	8.10	8.20	8.30	9.03	8.37	9.10	73.14	68.63	75.53	3.30	3.38	3.40	39.78	38.76	39.39	131.27	131.01	133.93	13.00	12.90	13.00	7.00	7.10	7.10	846.41	2972.63
R5	9.50	9.40	9.50	9.30	9.10	9.10	88.35	85.54	86.45	3.60	3.84	3.50	52.92	54.18	52.50	190.51	208.05	183.75	16.30	16.40	16.30	8.50	8.40	8.50	922.19	3416.47
D1	9.98	10.20	10.08	10.30	11.52	12.26	102.79	117.50	123.58	3.00	3.10	3.10	36.77	36.61	37.39	110.31	113.49	115.91	15.60	15.80	15.70	8.80	8.70	8.60	778.99	2683.02
D2	8.60	8.60	8.80	10.22	9.06	8.97	87.89	77.92	78.94	4.00	4.04	4.08	36.82	34.95	35.49	147.28	141.20	144.80	14.90	14.90	14.90	7.54	7.50	7.58	814.30	3081.94
D3	7.90	8.10	8.10	7.17	7.00	6.71	56.64	56.70	54.35	4.10	4.30	4.18	41.76	44.10	41.34	171.22	189.63	172.80	14.50	14.50	14.50	7.00	6.98	7.00	864.87	3443.36
D4	8.40	8.48	8.40	9.38	9.10	10.20	78.79	77.17	85.68	3.68	3.70	3.70	26.73	26.00	25.25	98.37	96.20	93.43	14.08	14.10	14.00	6.70	6.70	6.70	674.65	2700.53
D5	8.14	8.20	8.30	7.30	7.00	7.30	59.42	57.40	60.59	3.50	3.60	3.50	31.50	29.68	30.45	110.25	106.85	106.58	13.80	13.80	14.00	7.00	7.00	7.00	647.38	2439.07
G1	9.44	9.40	9.40	6.86	7.17	7.35	64.76	67.40	69.09	2.60	2.50	2.54	21.58	23.46	22.68	56.11	58.65	57.61	15.00	15.10	15.00	7.60	7.50	7.58	446.437	1662.52
G2	8.70	8.80	8.68	9.15	9.36	9.70	79.61	82.37	84.20	3.14	3.10	3.18	29.70	30.38	30.12	93.26	94.18	95.78	14.40	14.30	14.30	7.20	7.00	7.10	661.513	2543.10
G3	9.08	9.10	9.20	6.60	6.95	6.75	59.93	63.25	62.10	3.30	3.40	3.24	21.07	21.39	22.56	69.53	72.73	73.09	14.40	14.50	14.44	6.40	6.60	6.70	497.69	2068.54
G4	8.00	8.10	8.10	7.25	7.61	8.06	58.00	61.64	65.29	2.98	3.00	2.90	26.24	26.50	25.73	78.20	79.50	74.62	13.40	13.50	13.48	6.10	6.30	6.10	555.670	2300.73
G5	9.30	9.20	9.10	7.11	7.94	7.18	66.12	73.05	65.34	3.00	3.10	3.00	21.00	22.95	22.10	63.00	71.15	66.30	15.30	15.20	15.10	7.20	7.30	7.40	478.08	1873.73
M1	7.28	7.30	7.28	6.24	6.00	6.68	45.43	43.80	48.63	2.80	2.70	2.70	19.68	18.86	20.75	55.10	50.92	56.03	11.30	11.40	11.30	5.50	5.60	5.30	475.01	1852.80
M2	6.70	6.60	6.60	5.17	4.60	5.26	34.64	30.36	34.72	2.30	2.28	2.34	27.89	26.45	27.36	64.15	60.31	64.02	10.80	10.90	10.80	5.28	5.10	5.10	477.42	1887.13
M3	6.90	7.00	7.10	4.44	4.50	4.31	30.64	31.50	30.60	2.80	2.67	2.70	26.13	26.53	26.98	73.16	70.84	72.85	11.40	11.50	11.40	5.20	5.00	5.10	486.022	2057.75
M4	6.50	6.50	6.60	4.70	4.23	4.41	30.55	27.50	29.11	2.40	2.40	2.40	26.25	27.36	25.16	63.00	65.66	60.38	10.90	10.80	11.00	5.04	5.00	5.10	454.99	1848.10
M5	4.50	4.60	4.70	3.34	3.49	3.46	15.03	16.05	16.26	2.10	2.10	2.10	19.11	19.03	18.20	40.13	39.96	38.22	9.20	9.30	9.20	4.40	4.50	4.40	323.21	1239.61